Perceptual Affordances of Wall-Sized Displays for Visualization Applications: Color

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Abstract
Wall-sized displays offer the opportunity to display very large information spaces. Most data representations can be scaled to wall size but display walls are not simply big desktop monitors. We do not yet know how the perceptual affordances of a wall, such as the wide viewing angles they cover, affect how data is perceived and comprehended. In this paper we call for more studies on the perception of data on wall-sized displays and discuss–with the example of color–several aspects of wall setups that we hypothesize will most affect the perception of this visual variable.

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Information visualization, perception, wall-displays.

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous.

Introduction
Wall-sized displays (PowerWalls) engulf viewers in very large high-resolution information spaces. They are well suited for data analysis and visualization due to several inherent benefits: physical rather than virtual navigation affords a natural pan-and-zoom in the information space, an enlarged physical space in front of the display enables collaborative viewing and data analysis, and millions of

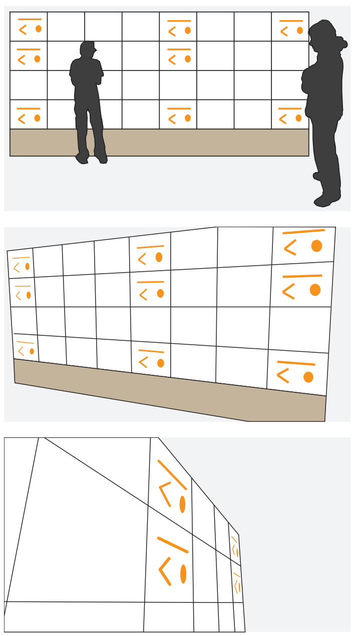

Figure 1: Two observers at different positions in front of a wall and how basic visual encodings look to them [6].

pixels support viewing tremendous amounts of data in one environment. To fully leverage wall-sized displays for *data analysis*, however, we need to design wall-sized *visualizations* based on a sound understanding of how such environments affect human perceptual and cognitive capabilities. One important criterion for the development of visualizations for wall displays is their immense physical size. It is not uncommon to see walls of over 5m (16ft) – 2m (6.5ft) in width and height [2], or even complete rooms covered on all sides by high-resolution displays [16].

With large display-walls, physical navigation becomes an important means of accessing visualizations [1]. Viewers choose close or far viewpoints to zoom in and out, and pan physically by moving left and right. This movement may involve a physical relocation or a change of head orientation. Thus, viewers fluidly and frequently switch viewing distances and angles which may lead to systematic discrepancies between the actual appearance of displayed information in physical space (measured by rulers) and its psychophysical appearance in a person's visual space. Our recent findings [6] indicate that this discrepancy can be very large (errors up to 60%) for quantitative estimations of certain visual variables and that perception depends largely on viewing positions and angles.

To build interactive visualizations for wall-displays, we need to characterize and model how perception and cognition are affected by this unique viewing environment. This will help us understand their benefits and limitations, especially when multiple people make use of the space. Based on such characterizations we can identify the visual representations that are best suited for these environments and provide guidelines for their design. With this paper we draw attention to the need for further fundamental research on understanding perception on wall displays.

Related Work

Some studies have already explored issues related to perception on wall displays. Endert et al. [10] discuss how a viewer's distance from a large display influences the visual aggregation of information. They found that colors aggregate well across viewing distances for visual search tasks. In earlier studies Yost and colleagues [19, 20] noted that spatial encoding (position) of information was particularly important in displaying large amounts of data, and that scaling visualizations beyond visual acuity affected user performance.They argue strongly for design guidelines that take visual aggregation and physical navigation into account. Jota et al. [11] studied the impact of viewing angles on pointing performance on walls and found that the visual size of an object affected performance more than its actual size. In previous work [5], we provided solutions to deal with change blindness by storing and replaying missed visual changes.

Recently we examined [6] the perception of some visual encodings (length, area, angle) seen under different distances and viewing angles (i. e. different viewer positions) and under conditions where viewers could move. Our findings indicate that when viewers are close to the wall and, thus, viewing angles are particularly steep, an increase of the horizontal displacement of items on the display can lead to errors up to 60% in some cases. Our viewers consistently overestimated the size of items, even in the case of the traditionally robust *length* and the underestimated *area* encodings [8]. Our findings also differ from a similar study by Wigdor et al. [17] on tabletops. When their large display was positioned at different inclinations, the researchers found no increase in error with horizontal placement. These differences indicate that we cannot easily generalize findings from perception research conducted on other setups to wall displays.

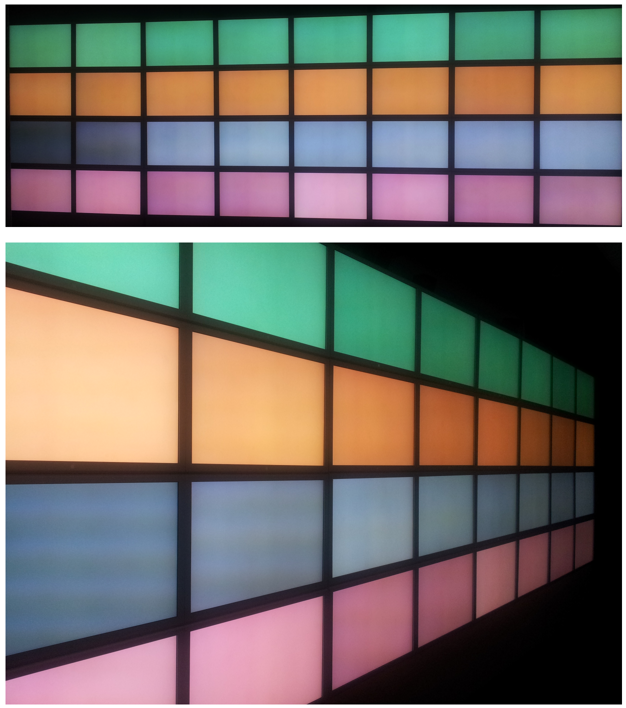

Figure 2: Change of color across the LCD screens of the WILD wall [2] as seen from two different viewpoints.

Studying Perception of Visual Variables for Wall-Sized Displays

Elementary graphical items such as points, lines, and areas are the main building blocks of information visualization applications [3]. They possess individual properties such as position, color, orientation, or size which are the visual variables defining them [8]. Any information visualization consists of an assembly of these elementary items and their variables. Thus, studying how visual variables are perceived, quantitatively measured, and compared, has helped build a basis for further studies on how these "assembled" visualization are perceived. For example, the basic understanding that humans are not very good at quantitatively comparing angles [8] is regularly cited as one of the reasons that bar charts are better than pie charts when quantitative comparison is required. A number of studies have contributed to our understanding of the perception of visual variables, but as we have shown [6], the unique viewing environment of wall-sized displays requires a re-assessment of these studies.

As an example of the many unique perceptual challenges of walls, we discuss the possible implications in regards to one visual variable—color. Almost all visualizations use color (hue and/or saturation) as an information channel. However, we do not yet have a good understanding about how the components of color are affected in wall-sized viewing environments. Moreover, we believe color perception is particularly impacted by the scale of wall-sized displays, making it a particularly important variable to study. Previous research suggests that the following factors will all influence color perception.

Multiple Projectors/LCDs

High-resolution wall-displays are currently made up by tiling projectors or LCD displays. Each display may exhibit individual variation in color calibration and consistency, making it hard to ensure a uniform color even within the same display in the case of projectors [15]. The age of projector lamps, for example, influences the brightness of a display and the settings of multiple machines driving individual LCD screens need to be synced to achieve similar colors [7]. To make matters worse, monitors and projectors have different brightness/contrast and color gamut. Thus, it is unclear how color perception findings will translate from one wall setup to the next.

Viewing Angle
The physical properties of LCD screens lead to color being perceived differently based on viewing angle. This has been demonstrated and exploited [12]. On LCD monitors, there is typically a measured viewing angle at which the contrast of the LCD falls below 10:1 [18]. It is at this point that color perception starts to change. On older screens, the angle at which color is perceived normally can be quite narrow. While screen technology has greatly improved in recent years, differences still exist between vertical to horizontal viewing angles (with horizontal typically being much better). Thus, as with our other visual variables [6], color perception may be impacted differently on high or low screens.

Viewing Distance
As discussed by Stone [14], size of objects matters for color perception. For example. small objects appear more distinct with strong color, while strong color on large objects is overwhelming. As viewers of a wall display visualization will adopt viewing positions at different distances from the screen, the same objects will cover different sizes on the retina. Thus, color perception may vary as one moves closer or further away from an object.

Room Conditions
Color perception is also influenced by conditions of the viewing environment. For example, a color will look differently depending on the kind of light shining on a display area. Rooms with fluorescent lighting, direct sunlight, windows behind, next to, or in front of the wall etc. may all differ. It is also possible that color may look differently depending on the room design, e. g. whether the walls are painted in a light or dark color [13]. It is unclear to what extent these environmental conditions influence color perception for visualization, even on a standard desktop monitor. For wall-sized viewing environments the effect may be smaller, greater, or not noticeable. We currently do not know.

Bezels
In our previous work we found that screen bezels had an influence on the quantitative estimation of the *position* and *length* variables, even if the objects tested did not cross between screens. If and how bezels can affect color is less clear. While it is known that color hue perception is influenced by surrounding color (contrast illusion), it is not clear whether bezels provide sufficient change in background color. For example, data points on a white background drawn immediately next to a large black bezel may be perceived as having a different color hue or saturation than the same data point drawn elsewhere.

A Call for Groundwork in Perception. . .
Given how many characteristics of wall-sized displays may influence visual variables such as color hue and saturation, the key question is whether we can build perceptual models to help us deal with changes in how a variable is perceived. In our previous work we found that the quantitative estimation of lengths, areas and angles was not correlated in a predictable way to the visual size of objects, but rather to a collection of factors, such as the viewer's distance from the wall and the vertical and horizontal placement of the objects. We subsequently began to suggest a model that fits the object's true magnitude to their perceived one. Similar investigations need to be carried out for color, and other visual variables. This includes taking into account a wide range of factors that may influence perception, such as the type of display or lighting in a room.

This ground work is an important first step in understanding how visualizations are affected by the varying position and viewing angles possible in front of wall-displays. Nevertheless, to acquire a complete picture we also need to investigate the effect of assembling visual variables to construct complete visualizations. For example, we want to know not only how size affects color perception but also whether the perception of an object's size is affected in turn by its color (irradiation illusion). Given that both size and color are also affected by wall-display environments, what is the overall effect of combining them in a visualization? Such questions regarding the assembly of visual variables must be answered if we are to have a clear understanding of how human visual perception is affected by these environments.

. . . and Interaction

Our discussion so far has focused on how visual perception is affected in wall-sized display settings, without taking into account the effect of interaction. If we have a good understanding of perception, can we use implicit or explicit interaction to correct possible negative effects?

Explicit Interaction

We can use explicit interaction to improve perception limitations. For example, if we can reliably identify visual distortion we can suggest interaction techniques that can help to alleviating specific perception limitations. We are currently adapting existing techniques (such as [4]) to bring remote content—that we know is being perceived incorrectly—closer to viewers.

Implicit Interaction

We may also be able to use implicit interaction to automatically deal with limitations. For example, de Almeida et al. [9] use viewers' position to simulate motion parallax and allow them to see behind bezels on a wall display. In the same way, it may be possible to track people in the space and make color corrections based on their position. The more accurate this tracking (e. g. tracking markers on viewers' heads), the more adapted our corrections can be. On the other hand, it is important to use tracking technology that is light-weight and invisible to the viewer, such as depth sensing technology, or tracking viewer's weight on the floor (although this may be less accurate). There is, therefore, a tradeoff between the quality of corrections we can make and viewers' comfort when conducting their analyses.

or Just Walking

Physical navigation when using walls was identified early on [10] as being very important for different types of tasks. In our work [6] we also found that walking, a very implicit interaction with the wall, improves accuracy in perception in general. But we observed that walking strategies changed the improvement factor, and some extreme participant strategies had no beneficial effect at all. A deeper understanding of perception can help us refine existing recommendations and help us take the best advantage of these environments.

Our knowledge of perceptual limitations can also help us improve interaction in wall-size display settings. For example, if we know that some areas of the display are severely distorted for one viewer, they can be used to place interactive controls for another. Clearly more work is needed to identify the interconnections between interaction and perception, a line of work we are currently pursuing.

Final Comments

We highlight the need for a deeper understanding of how human visual perception and cognitive capabilities are affected by wall-sized displays. We need to characterize and model visualization perception, especially in cases where multiple people are active at different locations within the space. We must be vigilant in exploring not only the effect of display size, but also the other factors that affect these environments. Finally, we need to further consider the interdependence between interaction and perception. These results can help us to clearly identify the interactive visualizations that are best suited for these environments and provide guidelines for their design.

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